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(54) Determination of the Location of a Submerged Marine Seismic Streamer

(57) The determination of the location of a submerged marine streamer 20 towed behind a seismic exploration vessel is effected by means of an array of at least three transponders 10, 12, 14 secured to the ocean floor which generate distinguishable acoustic pulses upon a command signal from the ship. These signals are received by acoustic receivers 34 housed in the streamer and by the ship. The distance to each acoustic receiver may be triangulated from the data generated.

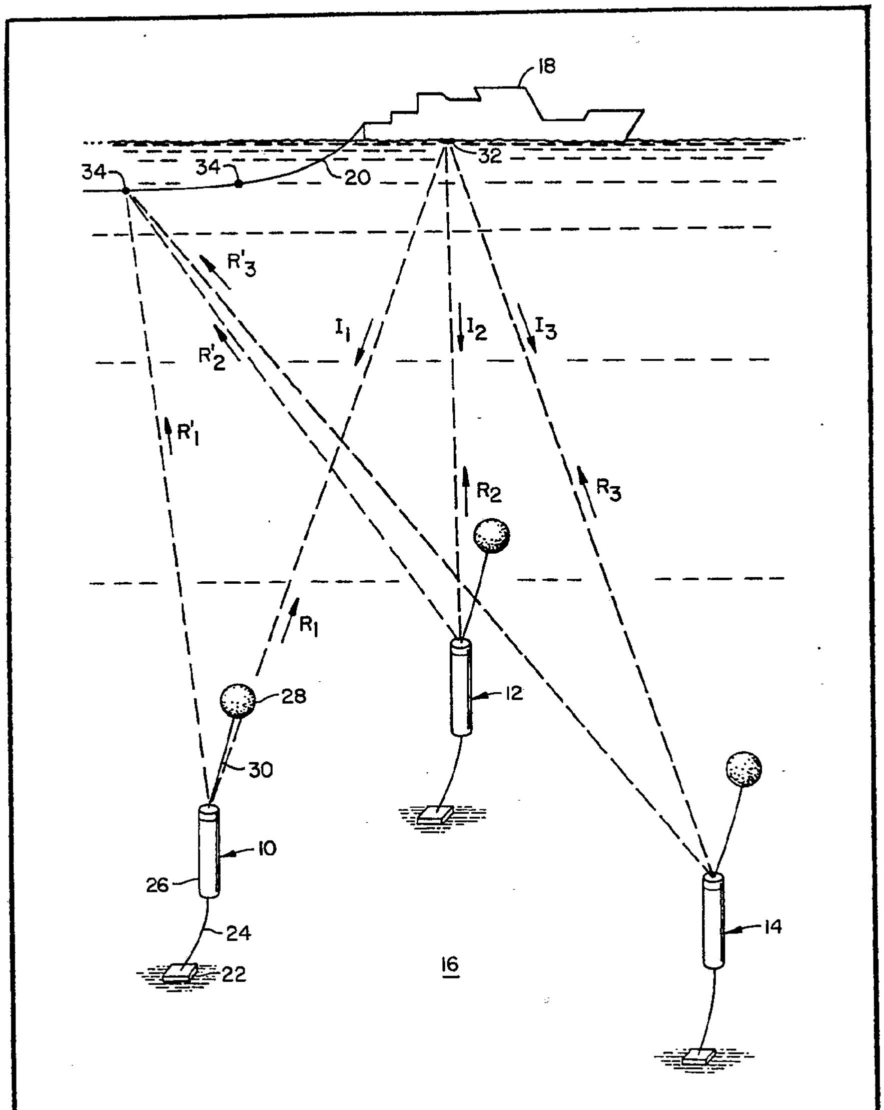

FIG.—1.

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The drawings originally filed were informal and the print here reproduced is taken from a later filed formal copy.

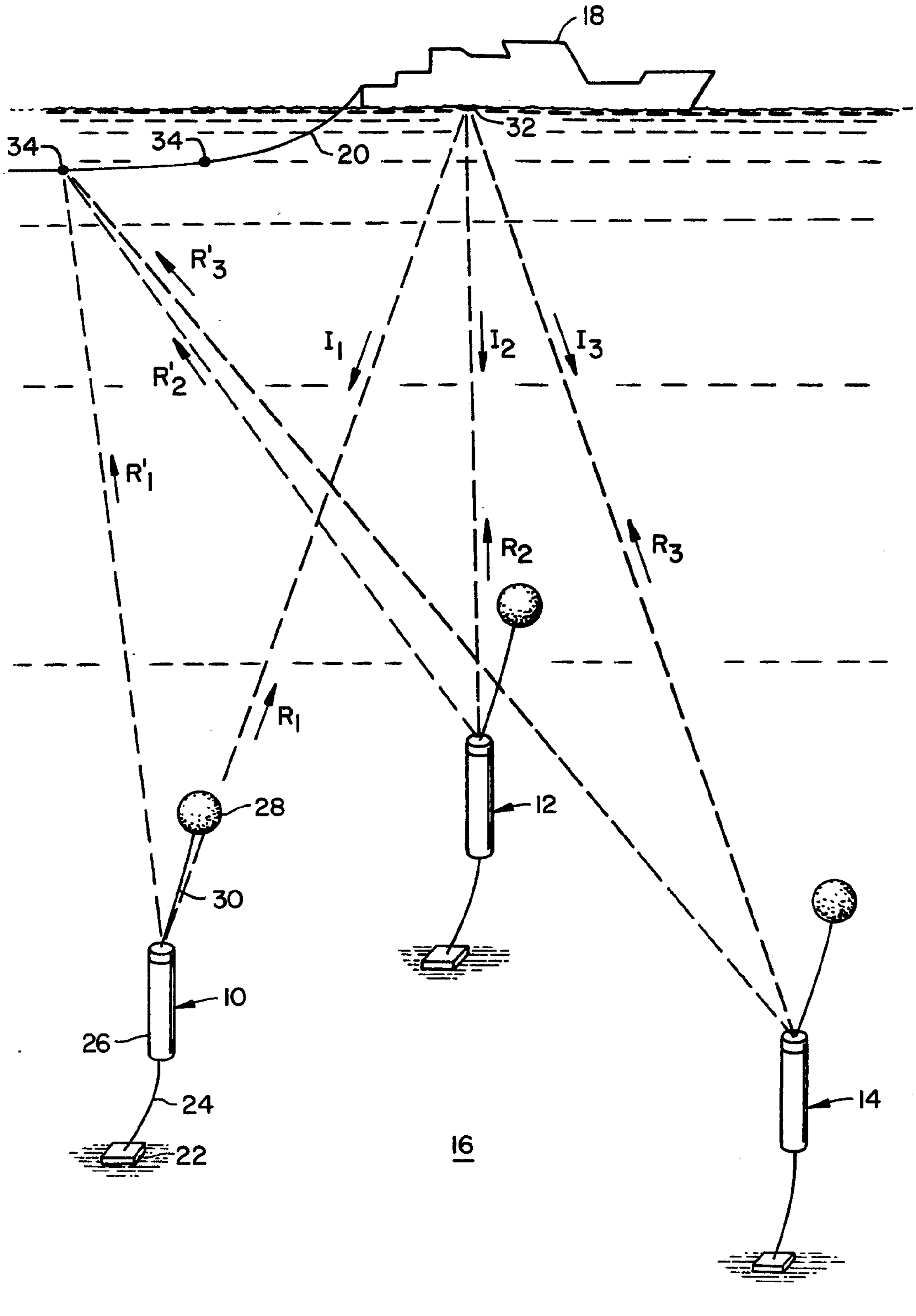

FIG._1.

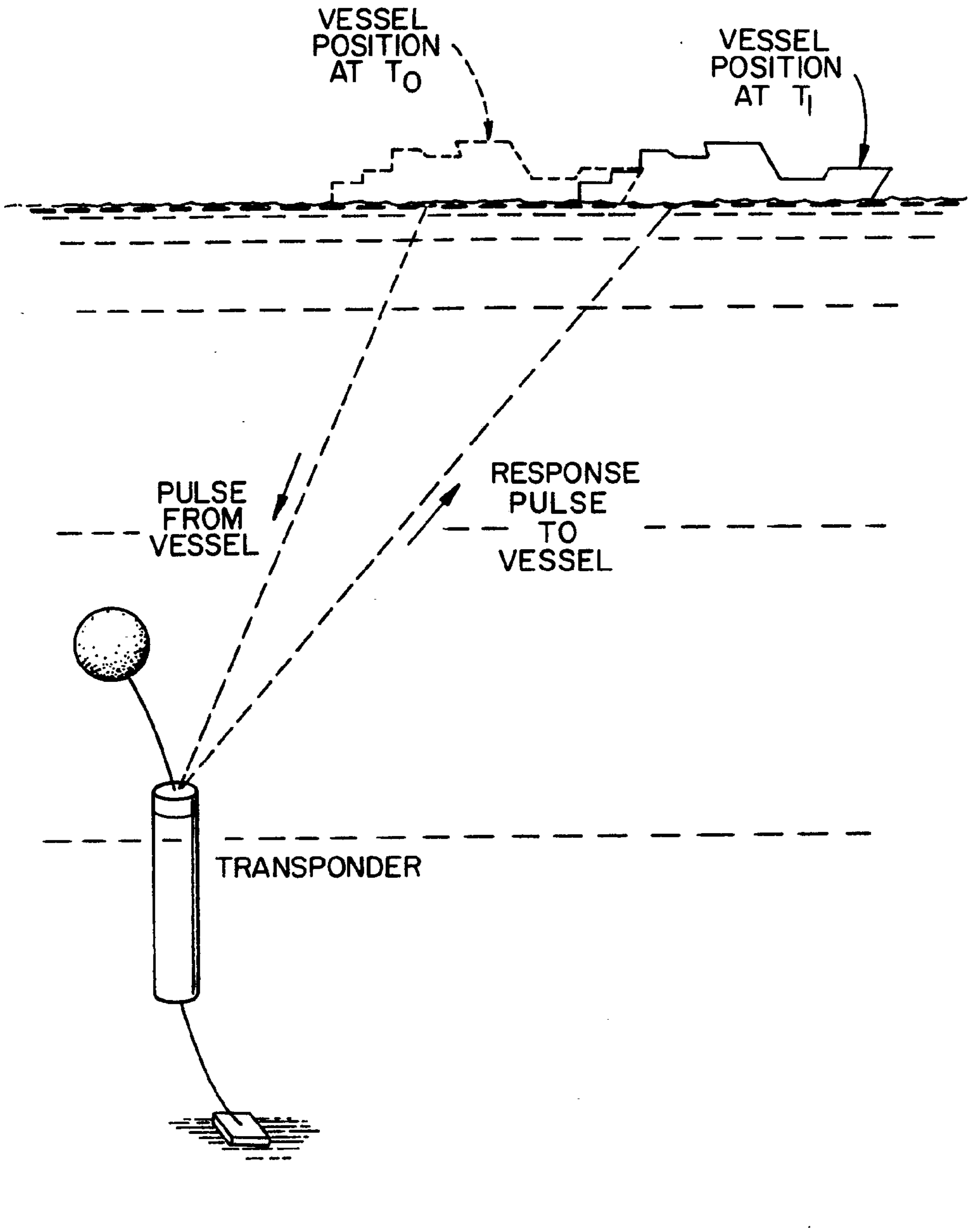
VESSEL
POSITION
AT T_O
VESSEL
POSITION
AT T_1
PULSE
FROM
VESSEL
RESPONSE
PULSE
TO
VESSEL
TRANSPONDER

FIG._2.

SPECIFICATION

Apparatus and Method for the Determination of the Location of a Submerged Marine Seismic Streamer

The present invention finds principal application within the field of marine seismic exploration. More particularly, the invention is concerned with means for accurately determining the position of a towed marine seismic streamer.

In marine seismic prospecting, an exploration vessel tows a seismic streamer having a plurality of pressure sensitive detectors, commonly referred to as hydrophones. A source of seismic energy, such as an air gun or an explosive charge, is used to propagate pressure waves through the water into the underlying sea floor. Part of the energy will be reflected by subfloor geological discontinuities and subsequently detected by the hydrophones as pressure variations in the surrounding water. The mechanical energy of these pressure variations is transformed into an electrical signal by the hydrophones and transmitted through the streamer to recording apparatus aboard the vessel. The collected data may then be interpreted by those skilled in the art to reveal information about the subsea geological formations.

For the signals to be meaningful, it is necessary to know the placement of the individual hydrophones at the time the pressure waves are detected. As the vessel is continuously moving and as the streamer may extend for thousands of feet behind the vessel, accurate location of the streamer hydrophones is difficult.

Various systems have been developed to provide accurate information as to the location of the vessel.

However, it is rare for the streamer to trail directly along the path of the vessel. While the streamer is attached to the stern of the vessel, the bulk of the streamer is submerged below the water surface through the action of depth controllers along the length of the streamer. As a result, the cross-track current velocity at the streamer depth may differ from the cross-track current affecting the vessel, thereby causing the streamer to trail at an angle to the vessel's course. Other factors, which are not necessary to enumerate, may also create a variance in the path of the streamer when compared to the vessel track.

One method of estimating the location of the streamer disclosed in the prior art relies upon the addition of a tail buoy radar reflector located at the end of the streamer. On-board radar systems may then be used under optimal sea conditions to find the end of the streamer and the location of the individual hydrophones interpolated. Such systems are generally unreliable however, and render the required data suspect.

A second method taught by the art relies upon very sensitive and expensive apparatus to measure the yaw and pitch angles of the streamer end adjacent the vessel. These data, coupled with magnetic compass headings taken along the streamer and the known depth of the streamer, permit one to empirically calculate the hydrophone locations.

It is an object of this invention to provide an accurate, alternative means for locating the submerged streamer which overcomes the deficiencies of the prior art.

The present invention relates to apparatus for use in determining the location of a submerged marine streamer towed behind an exploration vessel. The system comprises: means for initiating an acoustic command signal from the vessel; at least three transponders spatially located in known positions on the sea floor so as to provide distinct acoustic paths to the vessel and streamer, each of said transponders capable of responding to the command signal from the vessel by emitting acoustic pulses of distinctly different frequencies; a plurality of spaced receivers carried by the streamer capable of receiving the different acoustic pulses emitted by the transponders and individually relaying distinct signals along the streamer to the vessel responsive to said acoustic pulses; a vessel receiver capable of receiving and distinguishing the different acoustic pulses emitted from the transponders; and means for measuring the time interval from initiation of the command signal to receipt of the signals relayed from the spaced receivers housed by the streamer and the time interval from initiation of the command signal to receipt of the pulses by the vessel receiver from the transponders.

Preferably, the transponders are placed in a non-colinear relationship and each streamer receiver is serviced by a separate channel housed in the streamer for relaying signals to the vessel. The receivers may be either active or passive, but are preferably passive to minimize weight and expense. The apparatus may further comprise means for measuring the vessel's velocity with respect to the array of transponders situated on the ocean floor. Said means for measuring the vessel's velocity may include apparatus for measuring the Doppler shift in the frequency of the pulses generated by the transponders.

For a better understanding of the invention and to show how the same may be carried into effect, reference will now be made, by way of example, to the accompanying drawings, in which:—

Fig. 1 illustrates a transponder array shown in relationship to a surface exploration vessel towing a marine streamer; and

Fig. 2 diagrammatically illustrates the effect of shipment movement on the acoustic path between vessel and transponder.

The present invention required the placement of a plurality of acoustic transponders on, or adjacent, the ocean bottom. Preferably, the transponders will be positioned on the sea floor in noncolinear arrays of at least three transponders per array. Each transponder in a given triplet is preferably placed at a sufficient distance apart to give adequate range to the ship and streamer

receivers in a given water depth. While the present invention is concerned with location of the vessel and streamer with respect to a given array and not with respect to the actual geographical location, the latter relationship may be established from knowledge of the transponder placement. Well known methods are described in the art for determination of the transponder placement and calibration and are therefore not to be considered here.

Referring to Fig. 1 of the drawings, there is shown a single array of three acoustic transponders, indicated generally by reference numerals 10, 12 and 14, positioned on the sea floor 16. An exploration vessel 18 is shown on the surface towing a streamer 20.

Transponders of the type required are commercially available and normally comprise a base plate 22, resting on the sea floor, and a cable 24 attached between the base plate 22 and the transponder body 26. A float 28 connected to the transponder body 26 by means of a cable 30 maintains the transponder body 26 at an attitude above the sea floor determined by the length of cable 24. Float 28 also provides a means of retrieval if cable 30 is severed.

Vessel 18 is equipped with an acoustic transceiver 32 for sending command or interrogation acoustic signals through the water to the transponders and, in turn, receiving responsive signals therefrom. Preferably, all transponders in the array will respond to a single frequency signal emitted by the vessel's transceiver, however, coded signals may be generated to actuate the individual transponders from the vessel, if desired.

The marine streamer 20 is submerged below the water surface by a plurality of conventional depth controllers (not shown) and will normally house hydrophones (not shown), and depth sensors (not shown) which may be interrogated from the vessel for information.

In addition, the streamer will also house a plurality of acoustic receivers 34 spaced along the length of the streamer. Receivers 34 are capable of detecting the signals generated by the transponders and relaying identifiable responses along the streamer to the vessel. Normally the streamer will have individual channels leading from each receiver to the vessel for transmitting the information. Although the receivers may be active, or powered, it is preferred that the receivers be passive.

To determine the location of receivers 34 and thus the streamer position, the vessel's acoustic transceiver 32 is triggered to send an acoustic command signal. Upon receipt of the signal, after the delay in transmission time through the water, each transponder transmits an acoustic pulse of a distinguishable frequency. These pulses are detected by transceiver 32 and by the acoustic receivers 34 housed in the streamer. For the sake of clarity, acoustic travel paths are only shown in Fig. 1 of the drawing as dashed lines for the vessel transceiver, transponders, and a single receiver in the streamer. It should be understood, however, that similar paths could be drawn for each of the receivers housed in the streamer. Arrows I_1, I_2 and I_3 represent the command pulse travelling along the dashed lines from the ship to the transponders, arrows R_1, R_2, and R_3 represent the responsive pulses from the transponders to the vessel and arrows R'_1, R'_2 and R'_3 indicate the pulse lines of travel to the receiver housed in the streamer. Since the spatial positions of the transponders on the sea floor and the speed of sound through the water are known, the receiver position may be triangulated from knowledge of the travel time for each pulse from their respective transponders.

Suitable means aboard the vessel are provided to measure the time interval between the sending of the command signal and the receipt of the pulses from the transponders and the receivers.

In Fig. 2 of the drawings, there is illustrated a single vessel moving along the water's surface at time T_0 and at a subsequent time T_1. As shown therein, the vessel's transceiver initiates a pulse at time T_0 which travels in a straight line along the indicated path to the transponder. Upon receipt of the signal at time T_d the transponder transmits a pulse which is detected by the vessel transceiver at time T_1. From the figure it may be derived that the time, T_d, is given by the formula:—

$$T_d=T_0+\frac{(T_1-T_0)}{2}(1-\frac{\vec{v}}{c})$$

wherein $\vec{v}$ is the vessel's velocity with respect to the transponder and c is the propagation speed of the acoustic pulses.

The

$$\frac{\vec{v}}{c}$$

ratio may be determined in a number of ways. A preferred method, however, relies upon the measurement of the Doppler shift in the received frequency from the transponder. Naturally, in order to determine the velocity in this manner, the transponders must be capable of generating pulses of very stable frequencies and the vessel receiver must be capable of measuring the apparent change in the frequency.

The ratio may also be calculated from the rate of change of range in the direction of the transponders and the vessel. This range rate may be determined readily from knowledge of the vessel's position and speed with respect to the transponders.

The ratio

$$\frac{\vec{v}}{c}$$

for normal ship speeds during seismic operations will usually be less than .002, since $\vec{v}$ is about 3

meters per second and c is about 1,500 meters per second. If the

$$\frac{\vec{v}}{c}$$

term is dropped then:—

$$T_d = T_0 + \frac{(T_1 - T_0)}{2}$$

with an error of less 0.2%. An error of this magnitude may be acceptable for the ocean depths encountered in oil industry for some types of seismic operations.

Knowledge of the time t_d, for the initiation of the pulses from the transponders and the measured time of pulse detection by the receivers in the streamer as transmitted to the vessel permits the calculation of the distance from each transponder to each receiver. These distances may then be triangulated to give the location of each receiver in a streamer in real time by a shipboard computer or from the recorded data in post mission analysis.

Claims

1. Apparatus for use in determining the location of a submerged marine seismic streamer as it is towed by a marine seismic exploration vessel, which comprises:—

means for initiating an acoustic command signal from the vessel;

at least three transponders adapted to be spatially located in known positions on the sea floor so as to provide distinct acoustic paths to the vessel and streamer, each of said transponders being capable of responding to the command signal from the vessel by emitting acoustic pulses of distinctly different frequencies;

a plurality of receivers adapted to be carried in spaced apart relationship by the streamer and capable of receiving the different acoustic pulses emitted by the transponders and individually relaying distinct signals along the streamer to the vessel responsive to said pulses;

a vessel receiver capable of receiving and distinguishing the different sonic pulses emitted from the transponders; and

means for measuring the time interval from initiation of the command signal to receipt of the signals relayed from the spaced receivers along the streamer and the time interval from initiation of the command signal to receipt of the pulses from the transponders by the vessel receiver.

2. Apparatus as claimed in Claim 1, wherein in use said transponders are in a non-colinear relationship.

3. Apparatus as claimed in Claim 1 or 2, wherein said plurality of receivers is passive.

4. Apparatus as claimed in Claim 1, 2 or 3, wherein each of said plurality of receivers is adapted to be serviced by a separate channel in the streamer for relaying signals to the vessel.

5. Apparatus as claimed in Claim 1, 2, 3 or 4, and further comprising;

means for measuring the vessel's velocity with respect to said transponders.

6. Apparatus as claimed in Claim 5, wherein said means for measuring the vessel's velocity includes means for measuring the Doppler shift in the frequency of the pulses generated by the transponders.

7. Apparatus for use in determining the location of a submerged marine seismic streamer as it is towed by a marine seismic exploration vessel, substantially as hereinbefore described with reference to, and as shown in, the accompanying drawings.

8. A method of determining the location of a submerged marine seismic streamer towed by a marine seismic exploration vessel, which comprises:—

generating an acoustic command signal from the vessel;

receiving said acoustic command signal by a plurality of at least three transponders spatially located in known positions on the sea floor, which respond to the acoustic command signal by emitting acoustic pulses of distinctly different frequencies;

detecting the transponder acoustic response pulses with a plurality of spaced receivers carried by the streamer which relay distinct signals along the streamer to the vessel responsive to said pulses;

receiving and distinguishing the transponder acoustic pulses at the vessel; and

measuring the time interval from generation of the acoustic command signal to receipt of the signals relayed from the spaced receivers along the streamer and the time interval from generation of the command signal to receipt of the pulses at the vessel.

9. A method according to Claim 8, and further comprising:—

measuring the Doppler shift in the frequency of the pulses emitted by the transponders in order to determine the velocity of the vessel.

10. A method of determining the location of a submerged marine seismic streamer towed by a marine seismic exploration vessel, substantially as hereinbefore described with reference to the accompanying drawings.

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